Federal Aviation Administration

Ground Based Augmentation System

Performance Analysis and Activities Report

Reporting Period: July 1 – September 30, 2016

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1. Introduction

The Ground Based Augmentation System (GBAS) team under the direction of the Navigation Branch (ANG-C32) in the Engineering Development Services Division in the Advanced Concepts and Technology Development Office at the Federal Aviation Administration's (FAA) William J Hughes Technical Center (WJHTC) provides this GBAS Performance Analysis / Activities Report (GPAR).

This report identifies the major GBAS related research, testing, and validation activities for the reporting period in order to provide a brief snapshot of the program directives and related technical progress. Currently, the GBAS team is involved in the validation of the GAST-D ICAO SARPs, GBAS ILS/VDB interference testing, supporting system design approval activities for an update to the CAT-I approved Honeywell International (HI) Satellite Landing System (SLS-4000) and future CAT-III capable SLS-5000, and maintaining six Ground Based Performance Monitors (GBPMs) and a prototype GAST-D Honeywell Satellite Landing System at Atlantic City International Airport (ACY). Other milestones achieved this quarter include the first Cargolux GBAS landing at Houston (IAH) and the completion of a GBAS demonstration at San Francisco Int'l Airport (SFO) by Boeing, Delta, United & local FAA personnel.

Objectives of this report are:

a) To provide status updates and performance summary plots per site using the data from our GBPM installations
b) To present all of the significant activities throughout the GBAS team
c) To summarize significant GBAS meetings that have taken place this past quarter
d) To offer background information for GBAS

2. GBAS Updates by Site

The GBPM was designed and built by ANG-C32 to monitor the performance of GBAS installations. There are currently six GBPMs in use. They are located in Newark New Jersey (EWR), Houston Texas (IAH), Moses Lake Washington (MWH), Rio de Janeiro Brazil (GIG), and two in Atlantic City New Jersey (ACY). The GBPM is used to monitor the integrity, accuracy, availability, and continuity of the FAA's LAAS Test Prototype (LTP) and Honeywell's SLS-4000.

The plots in each of the following sections utilize a compilation of data collected at one minute intervals.

Note on Plots:

The first plot shows the site's availability, i.e. the user's ability to use the system for the defined procedures. An outage, or loss in availability, occurs when the protection levels (LPL and VPL) exceed the alert limit, or when the system is down for reasons other than planned maintenance. The satellite constellation data used to generate the data shown in this plot is derived from the Almanac.

The second plot shows satellite elevation versus time (UTC) for the site on a single day of the quarter. Typically, a day that falls within the middle of the quarter is chosen to represent this plot for each of the sites.

The next two plots show the site's lateral accuracies and lateral protection level (LPL) versus error respectively. The first plot compares the lateral accuracies for GBAS and GPS. For the lateral protection level (LPL) versus error plot, data points should ***never*** appear in the dark area of the plot; this would indicate that the error exceeds the protection levels. The data used to generate these plots is from the GPS receiver in the FAA-owned Ground-Based Performance Monitor (GBPM) on-site.

The final two plots show the site's vertical accuracies and vertical protection level (VPL) versus error respectively. The first plot compares the vertical accuracies for GBAS and GPS. For the vertical protection level (VPL) versus error plot, data points should ***never*** appear in the dark area of the plot; this would indicate that the error exceeds the protection levels. The data used to generate these plots is from the GPS receiver in the FAA-owned Ground-Based Performance Monitor (GBPM) on-site.

For live, up-to-date data, refer to http://laas.tc.faa.gov. A more detailed description of the GBPM configuration can be found in Appendix D of this report.

2.1 EWR SLS

- Newark Liberty Int'l Airport has a Honeywell SLS-4000 that was granted operational approval on September 28, 2012. The ground station is currently configured in CAT I – Block I mode.
- Since the EWR SLS-4000 went live, there have been a total of 1519 GBAS approaches conducted at EWR. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), and Lufthansa (A380 Airbus).

Figure 1 - EWR SLS-4000 Configuration

2.1.1 Real Time Performance Data

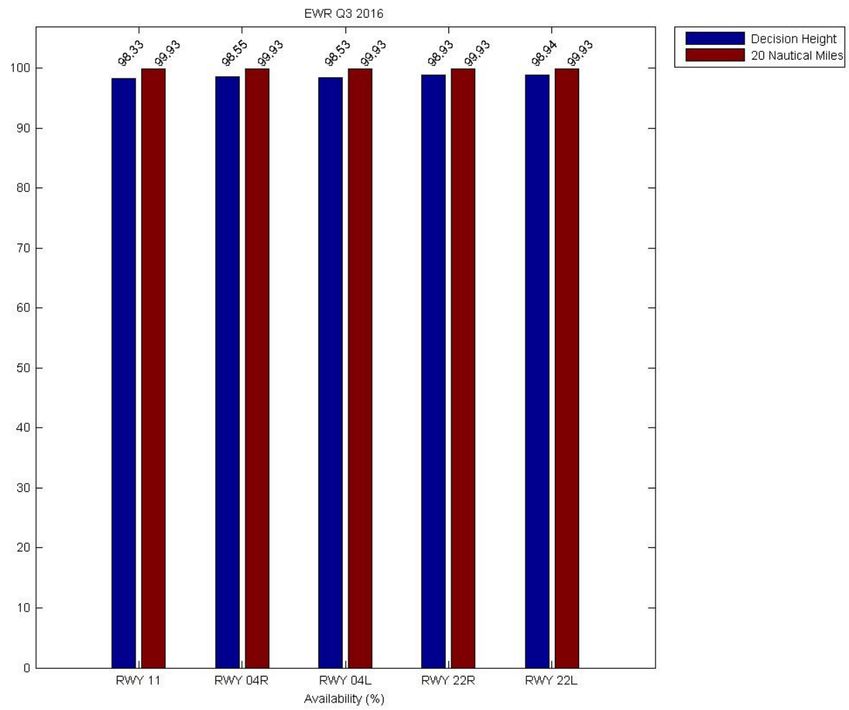

Figure 2 - EWR Availability

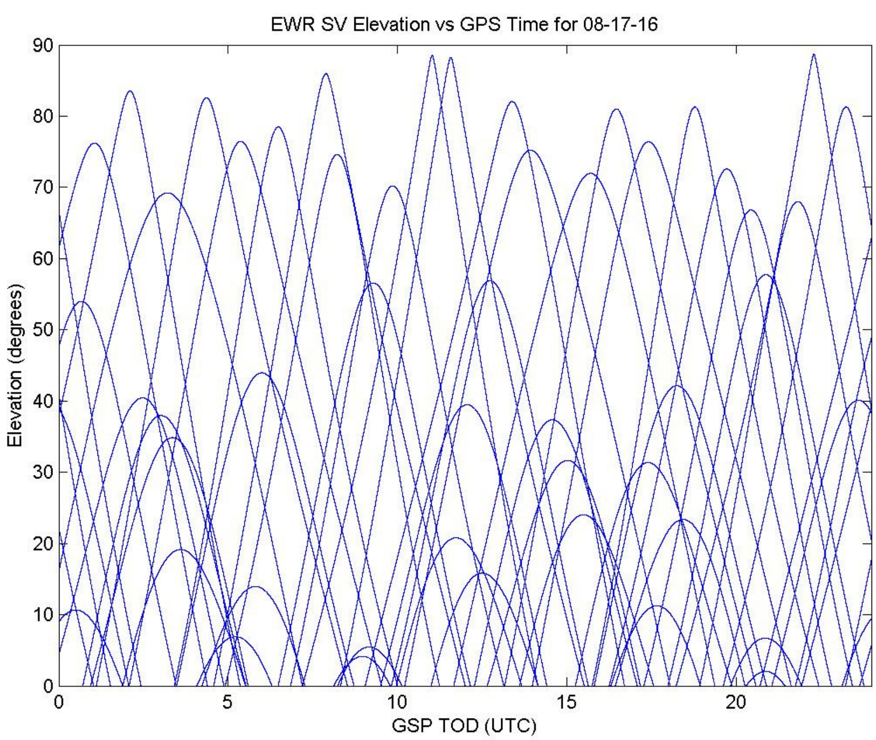

Figure 3 - EWR SV Elevation vs GPS time 08/17/16

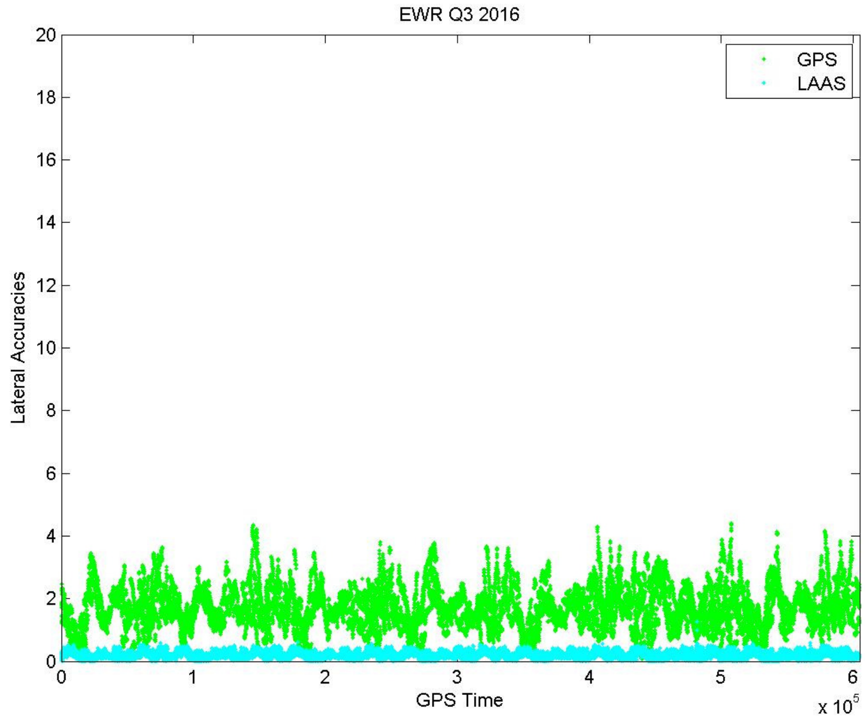

Figure 4 - EWR Lateral Accuracy

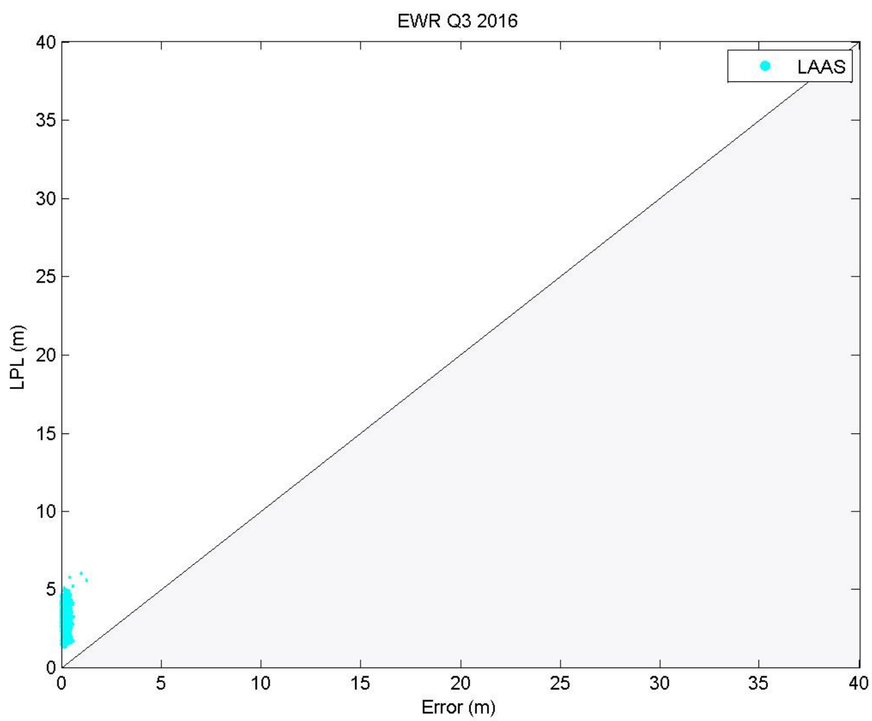

Figure 5 - EWR Lateral Protection Level (LPL) vs. Error

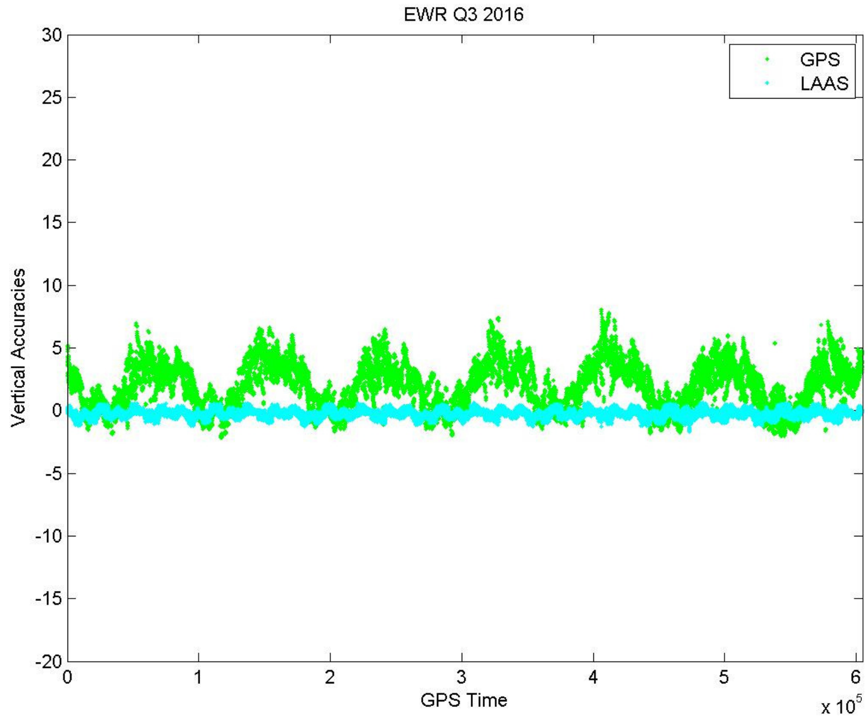

Figure 6 - EWR Vertical Accuracy

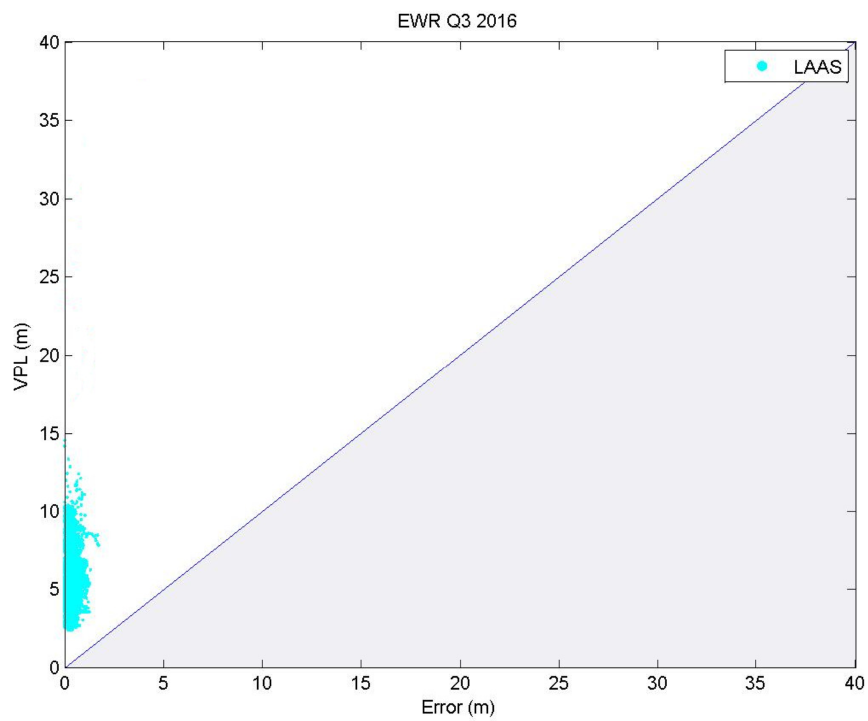

Figure 7 - EWR Vertical Protection Level (VPL) vs. Error

2.2 IAH SLS

- George Bush Intercontinental Airport in Houston, TX has a Honeywell SLS-4000 that was granted operational approval on April 22, 2013. The ground station is currently configured in CAT I – Block I mode.
- Since the IAH SLS-4000 went live, there have been a total of 1632 GBAS approaches conducted at IAH. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), Cathay Pacific (Boeing 747-8), Emirates (A380 Airbus), Carlgolux and Lufthansa (A380 Airbus).

Figure 8 - IAH SLS-4000 Configuration

2.2.1 Real Time Performance Data

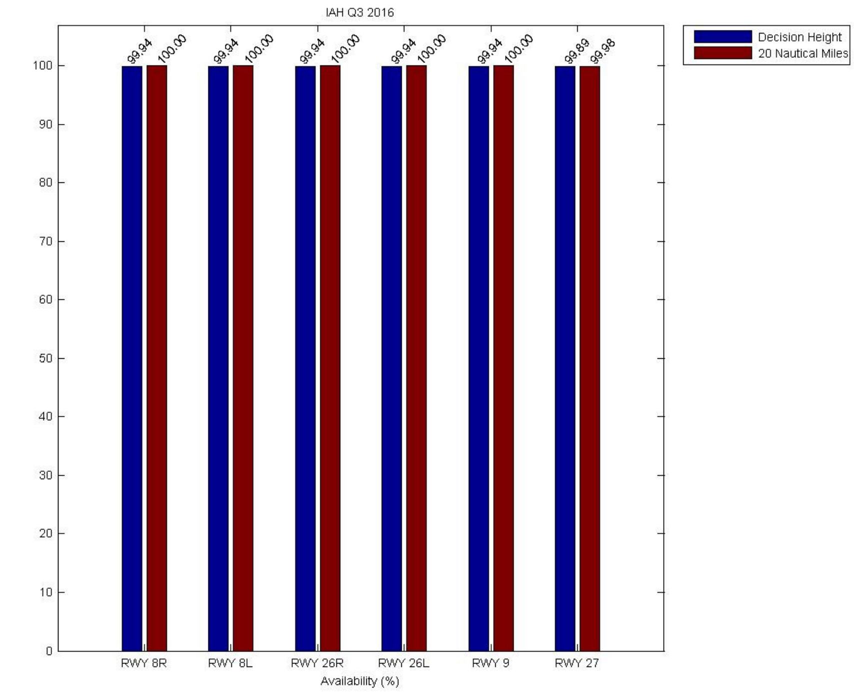

Figure 9 - IAH Availability

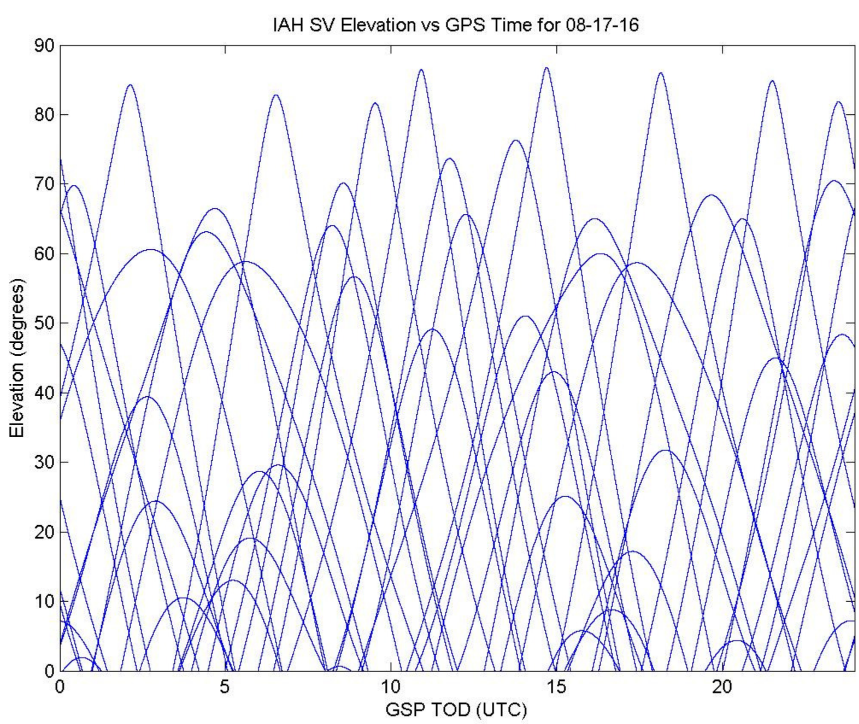

Figure 10 - IAH SV Elevation vs GPS time 08/17/16

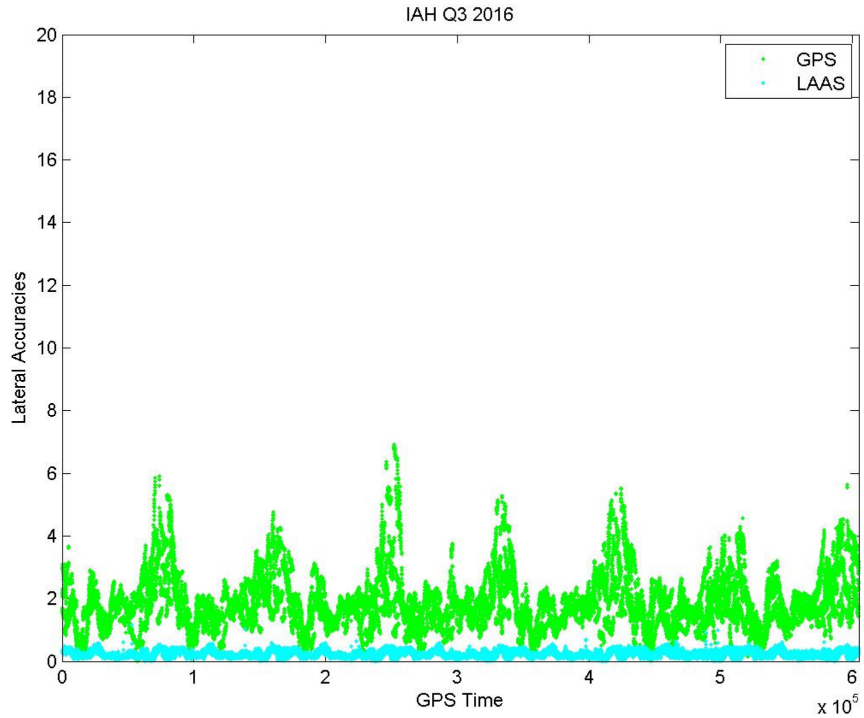

Figure 11 - IAH Lateral Accuracy

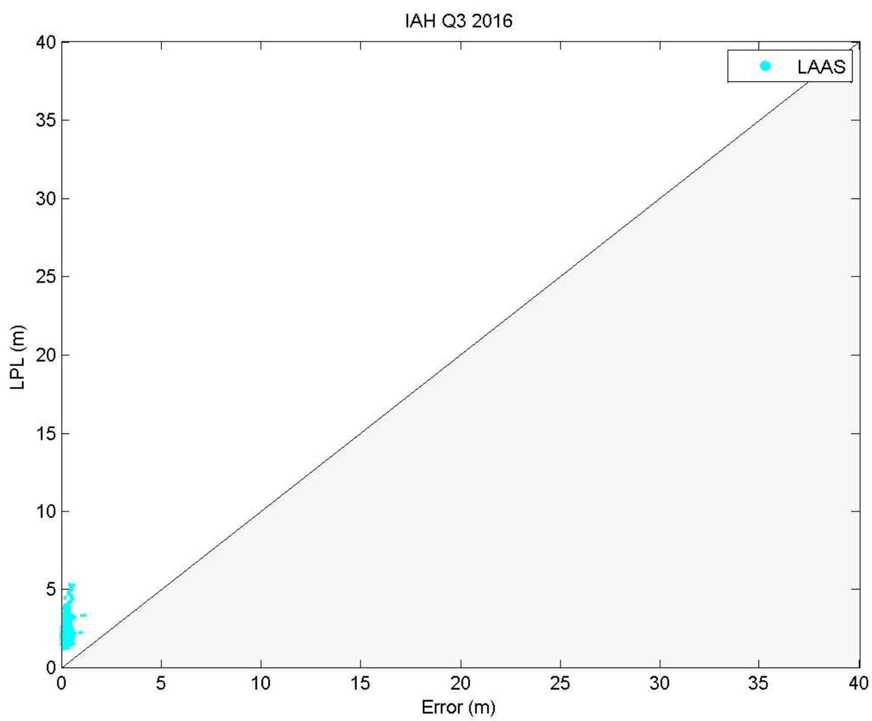

Figure 12 - IAH Lateral Protection Level (LPL) vs. Error

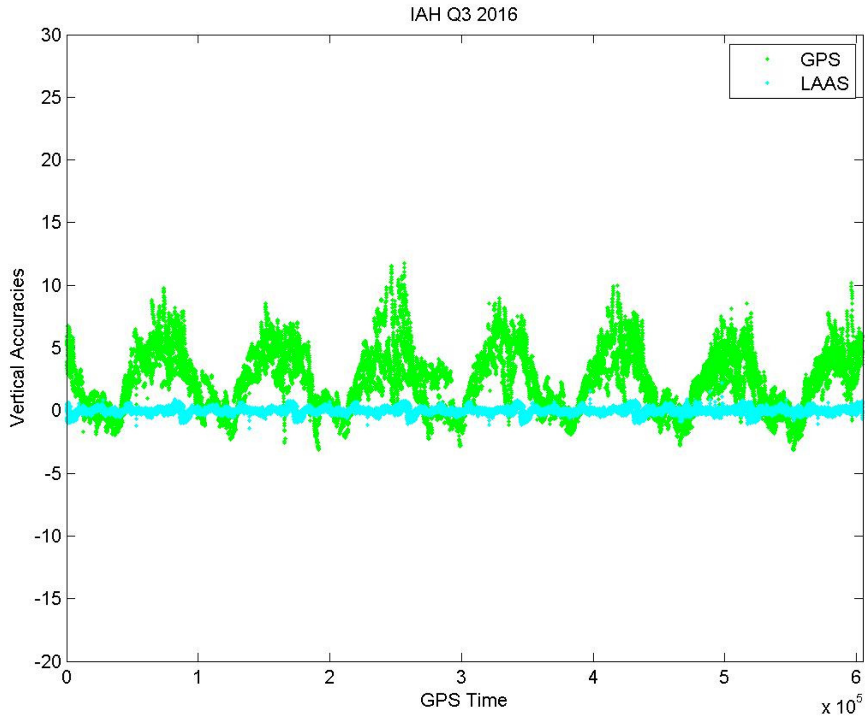

Figure 13 - IAH Vertical Accuracy

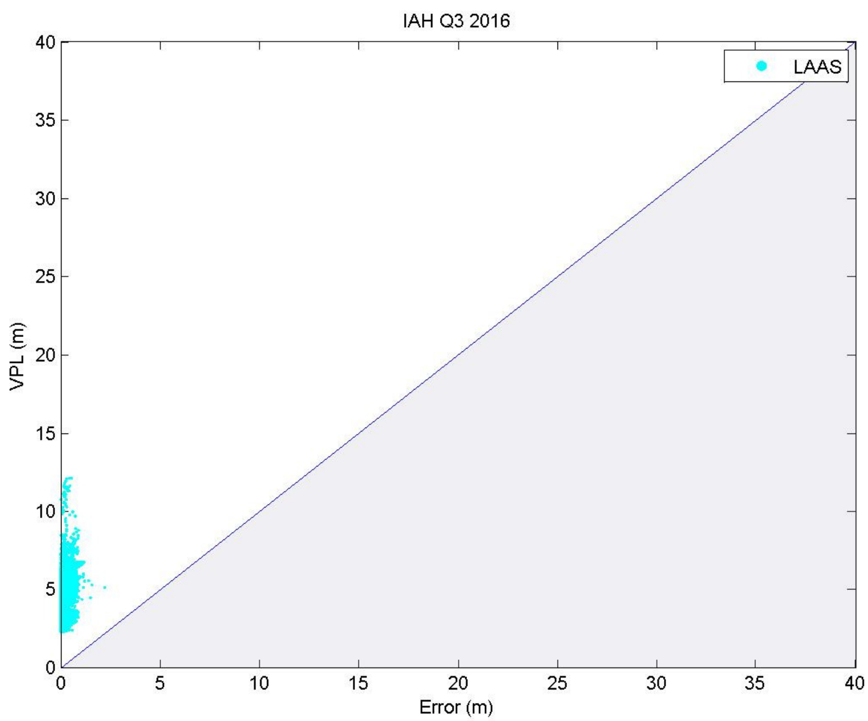

Figure 14 - IAH Vertical Protection Level (VPL) vs. Error

2.3 MWH SLS

- Grant County Airport in Moses Lake, WA has a private-use Honeywell SLS-4000 owned by Boeing that was granted operational approval on January 9, 2013. The ground station is currently configured in CAT I – Block I mode.
- Boeing uses this site for aircraft acceptance flights and production activities
- Boeing has also operated this site in a prototype GAST-D mode for flight testing to support GAST-D requirements validation
- While Grant County Airport (GEG) is a public use airport, it has no commercial flights
- This system requires a significant amount of multipath masking which can affect the constellation geometry at times, causing inflated protection levels and error, and a slight decrease in system availability.

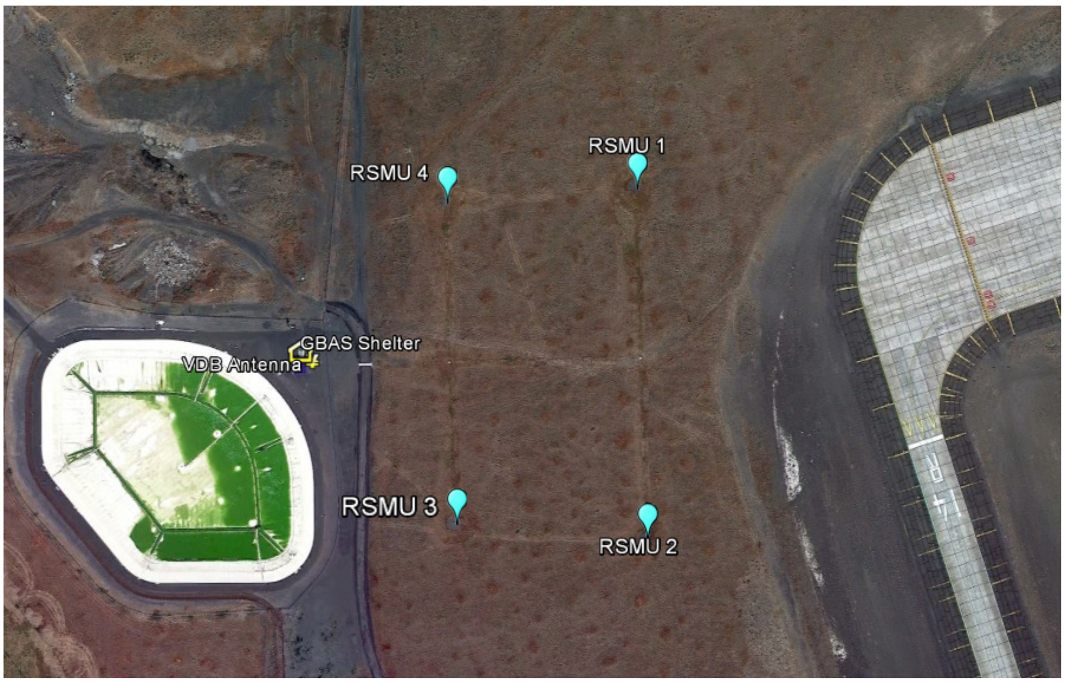

Figure 15 - MWH SLS-4000 Configuration

2.3.1 Real Time Performance Data

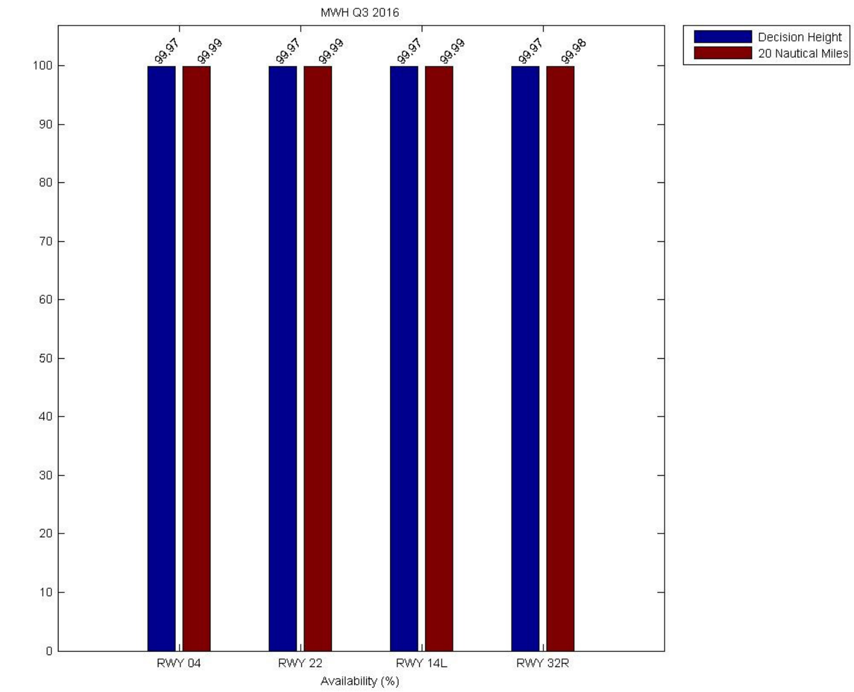

Figure 16 - MWH Availability

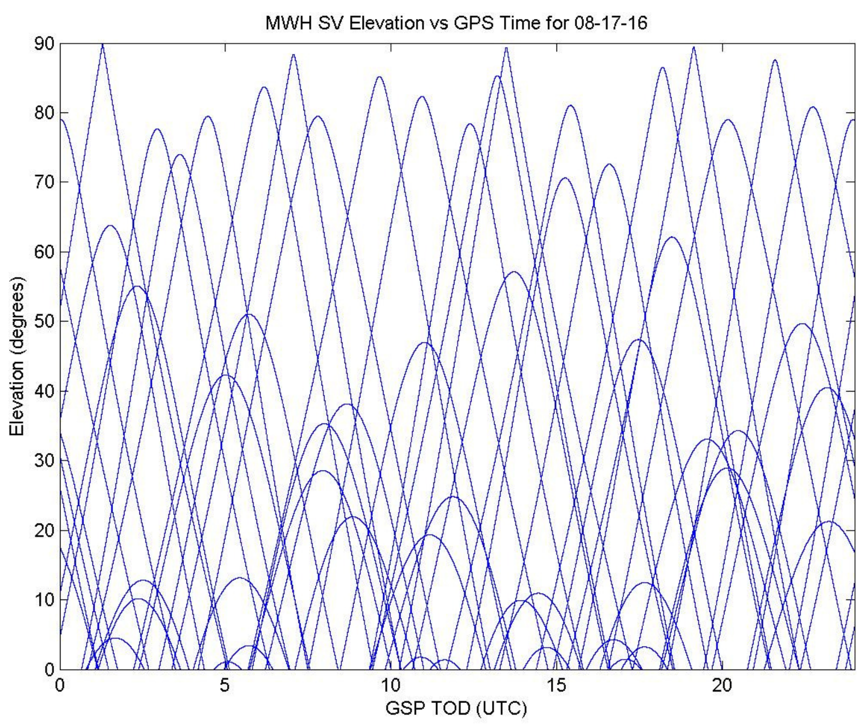

Figure 17 - MWH SV Elevation vs GPS time 08/17/16

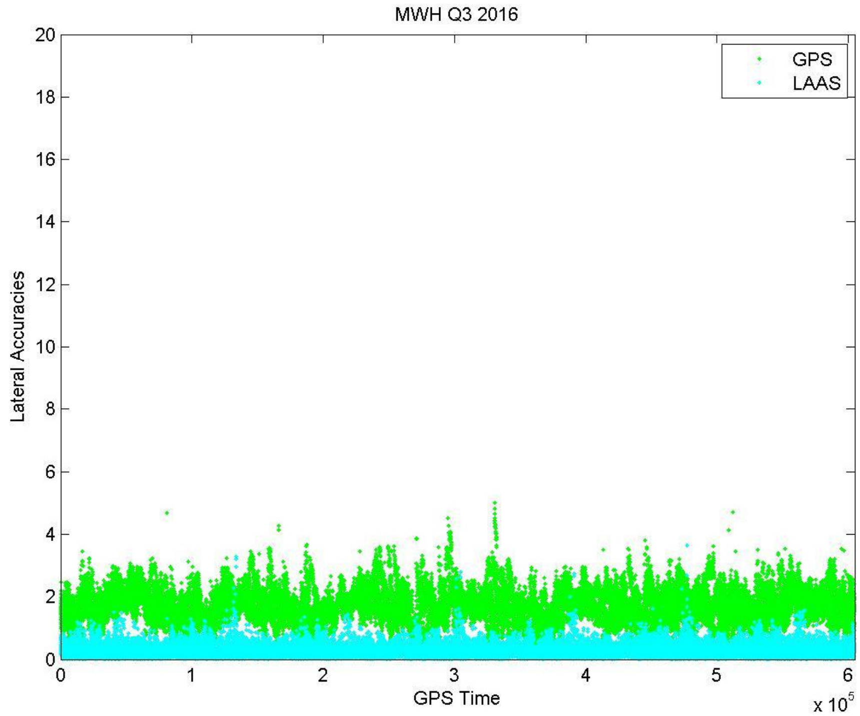

Figure 18 - MWH Lateral Accuracy

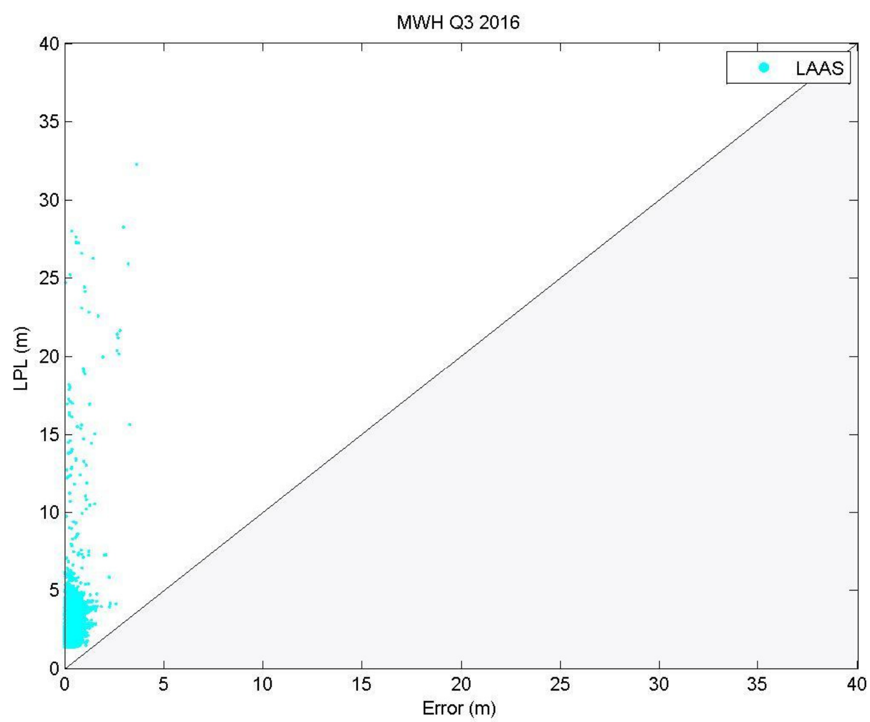

Figure 19 - MWH Lateral Protection Level (LPL) vs. Error

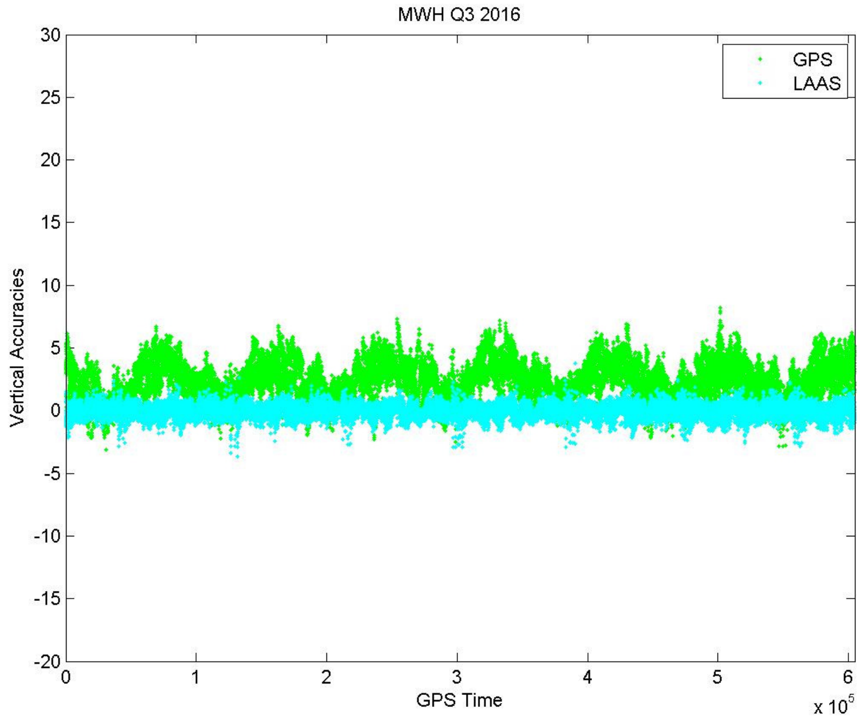

Figure 20 - MWH Vertical Accuracy

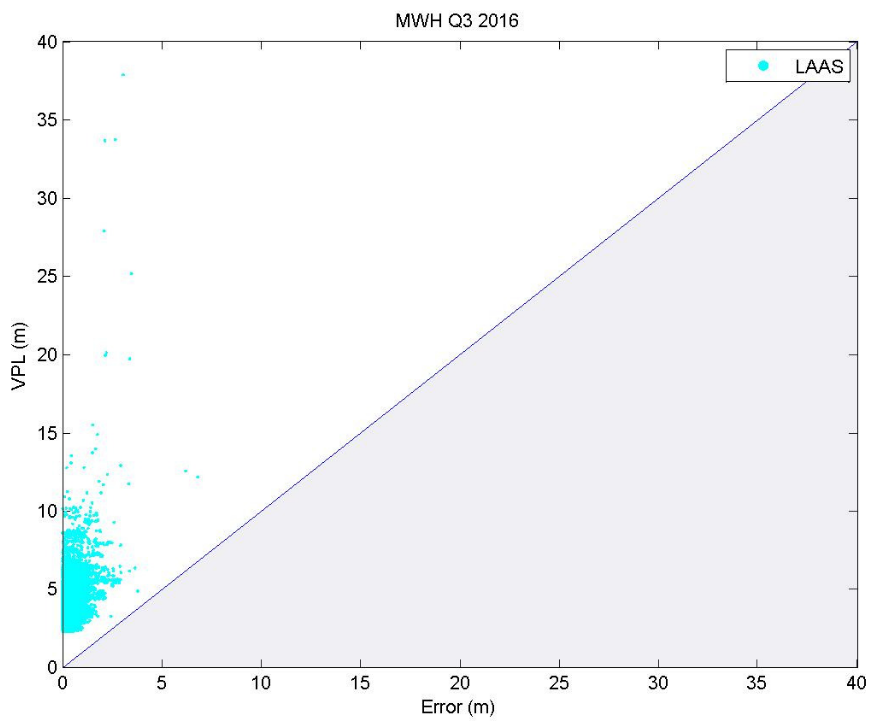

Figure 21 - MWH Vertical Protection Level (VPL) vs. Error

2.4 Rio de Janeiro Brazil

- The Rio de Janeiro GBAS is a Honeywell SLS-4000 operating in a CAT I – Block II prototype mode. The site was down due to maintenance issues during all of Q3.
- The antenna on the Brazil GBPM is less robust than the other sites, therefore satellites below 11 degrees may not be tracked as consistently
- The FAA-owned Ground-Based Performance Monitor (GBPM) remained in normal operation throughout Q3.

2.4.1 Real Time Performance Data

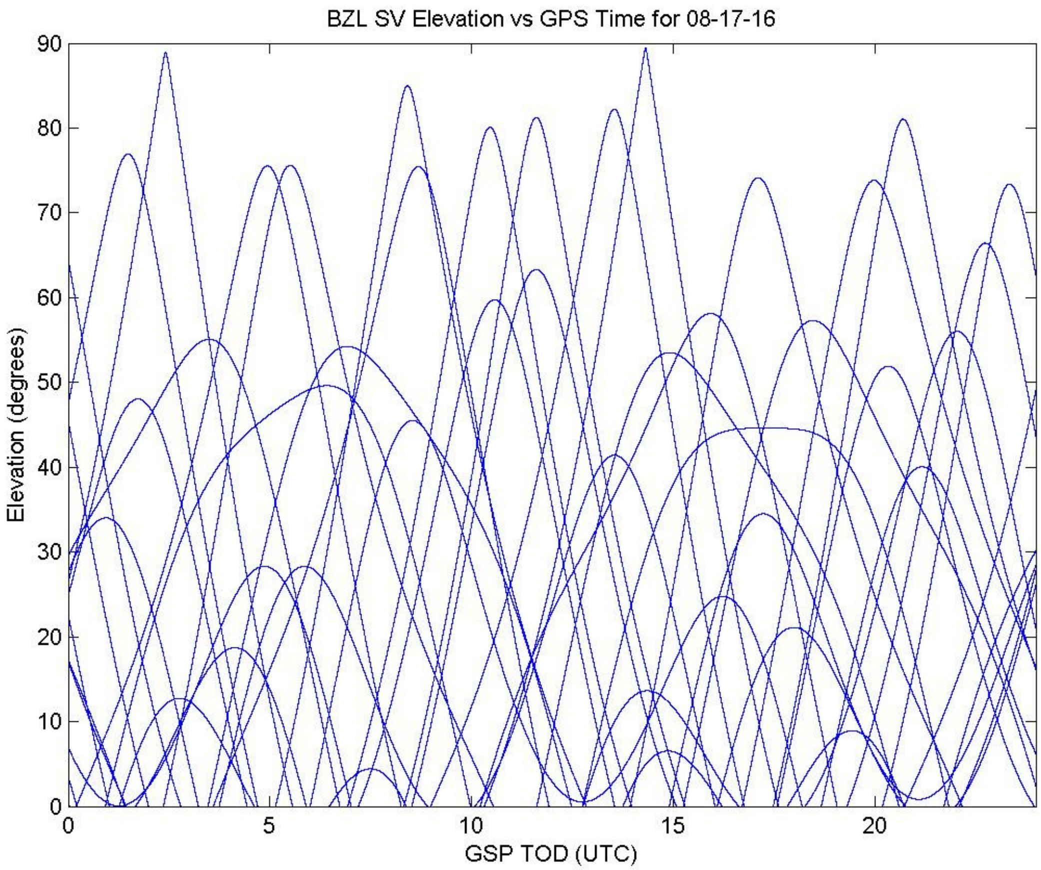

Figure 22 - BZL SV Elevation vs GPS time 08/17/16

2.5 ACY SLS

- The KACY ground station operates in either CAT-I Block II mode, or in CAT-III prototype mode.
- RSMUs 5 & 6 are not used in CAT-I mode and are part of the GAST-D/CAT-III prototype system.
- NOTE: Due to flight testing at the FAA William J. Hughes Technical Center, a total of two (2) days were removed from the ACY Real Time Performance Data plots shown in **Section 2.5.1** (07/06 – 07/07/2016). This also includes configuration down-time in preparation for said flight tests. Other data that was removed includes routine maintenance of the Honeywell SLS-4000 Ground Station.
- See **Section 3.4** for additional details on the tests performed this quarter.

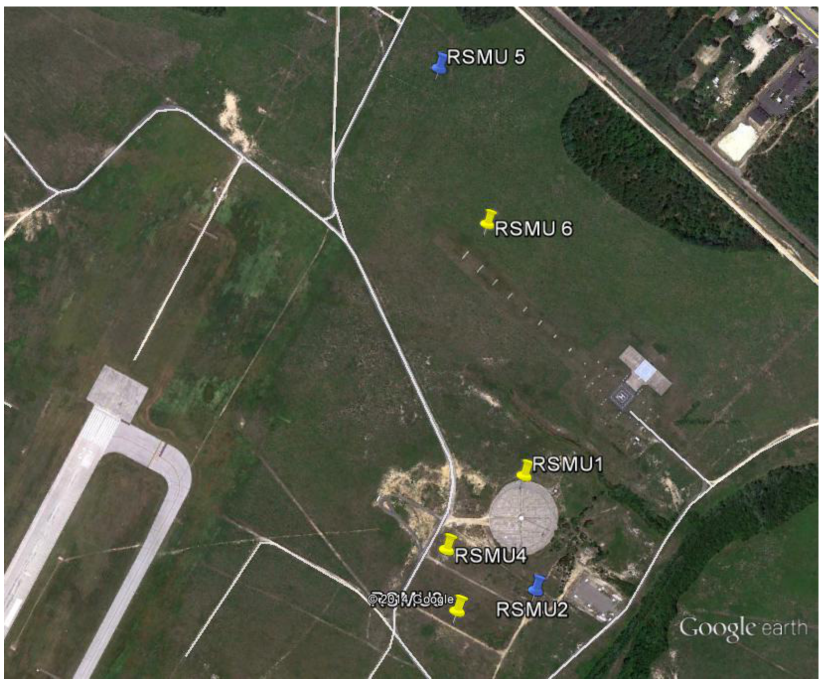

Figure 23 - ACY SLS-4000 Configuration

2.5.1 Real Time Performance Data

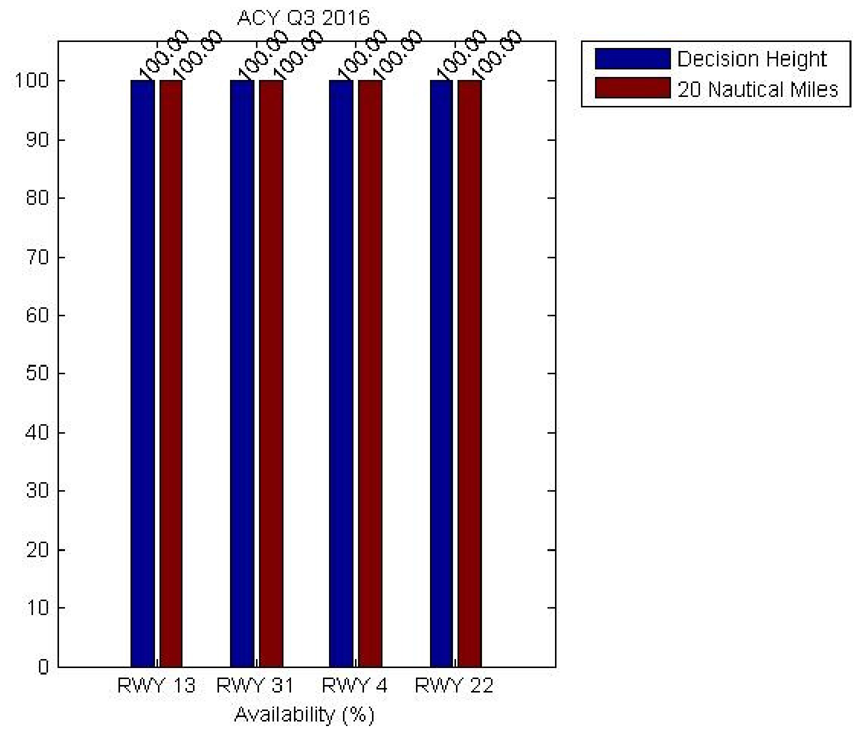

Figure 24 - ACY SLS Availability - The data shown is based upon times when the SLS was transmitting in a nominal mode

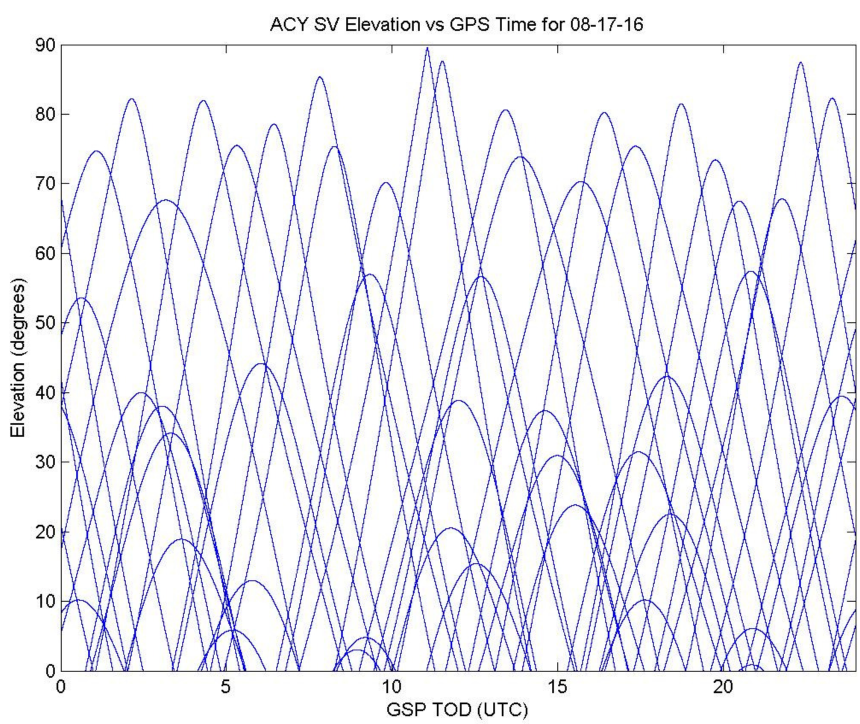

Figure 25 - ACY SV Elevation vs GPS time 08/17/16

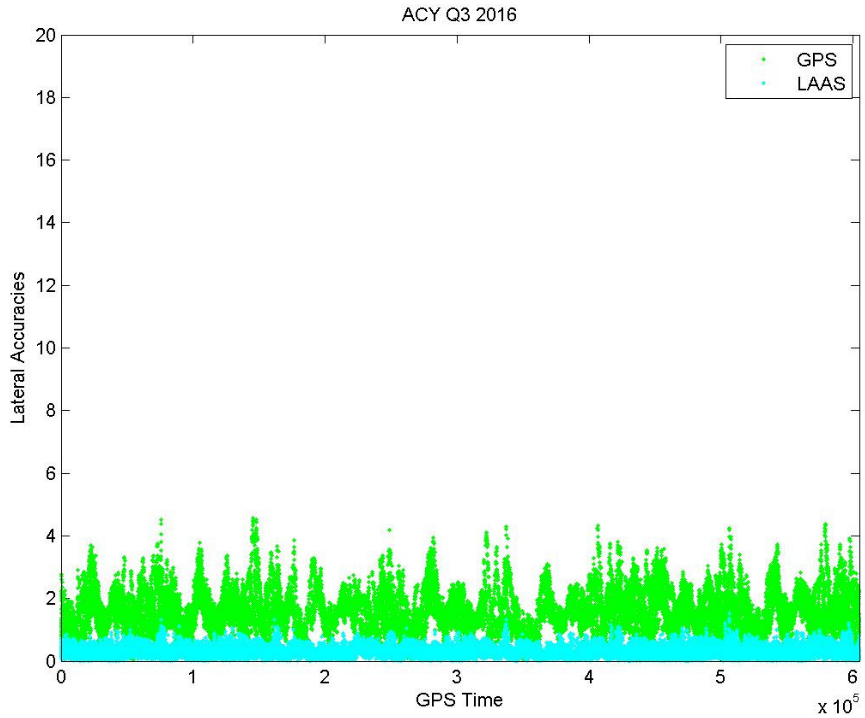

Figure 26 – ACY SLS Lateral Accuracy

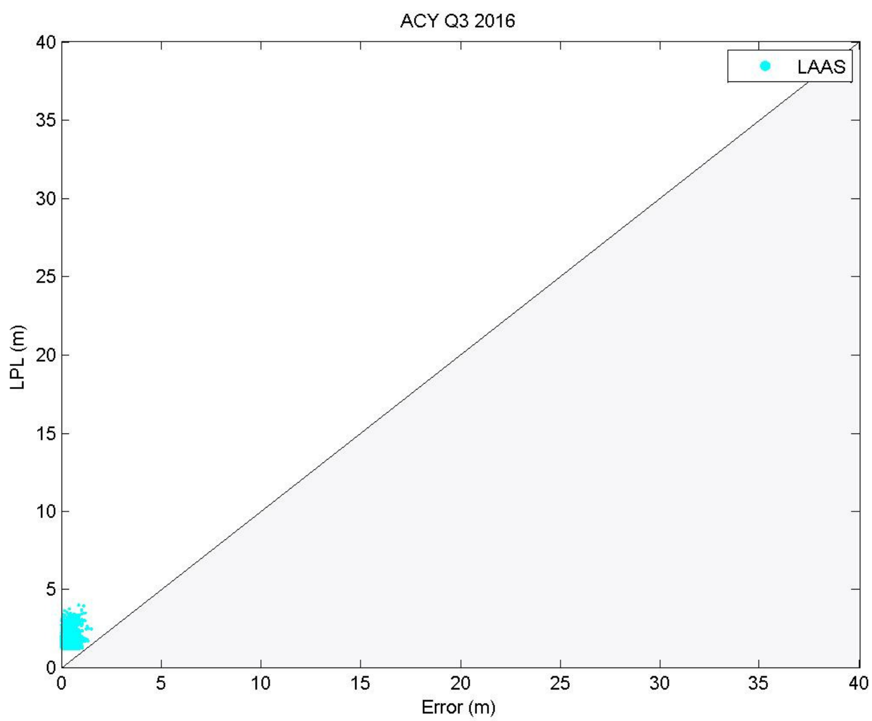

Figure 27 - ACY SLS Lateral Protection Level (LPL) vs. Error

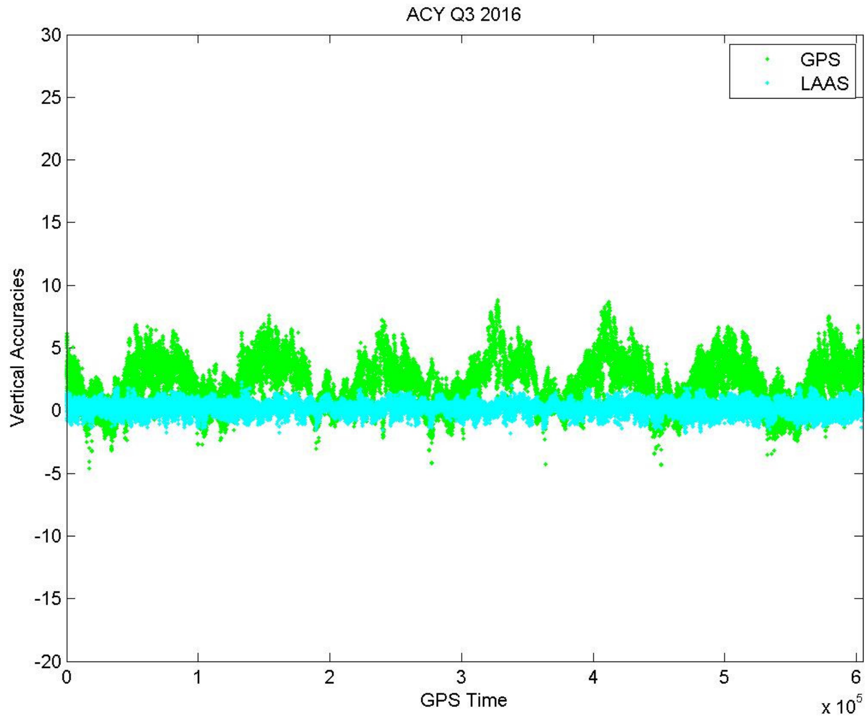

Figure 28 - ACY SLS Vertical Accuracy

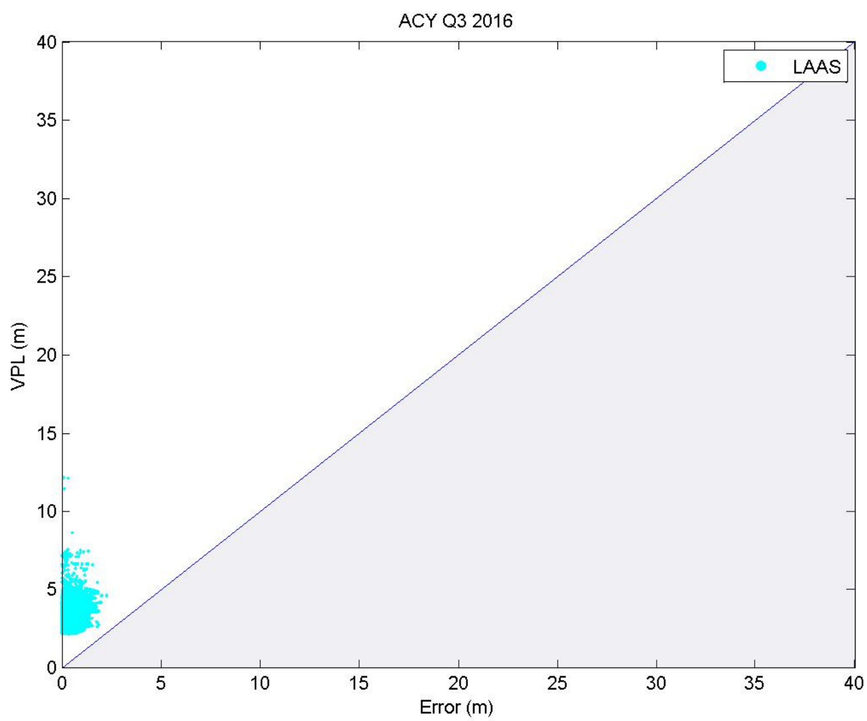

Figure 29 - ACY SLS Vertical Protection Level (VPL) vs. Error

2.6 LTP ACY

- At the time of this reporting, the LTP is being used in limited capacity for testing purposes only.
- The LTP was used to broadcast the Undesired Signal during the VDB Interference Flight Testing at the FAA William J. Hughes Technical Center. The Flight Tests were ongoing starting on 04/05/2016 through 07/07/2016. See **Section 3.4** for additional details.
- See Appendix C for a full description of the LTP configuration.

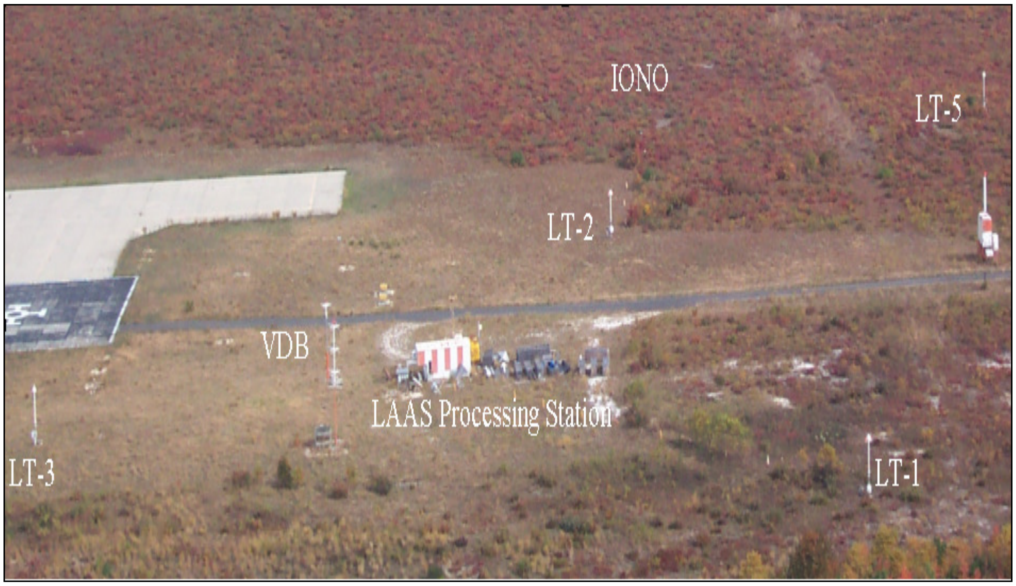

Figure 30 - Aerial View of LTP Configuration

3. Research, Development, and Testing Activities

3.1 GBAS GAST-D Validation Status Update

The DSigma Ad-Hoc group processed data to determine a noise sigma and threshold for the airborne monitor. Due to discrepancies in the prototype INR receiver, the FAA is reprocessing its DSigma data using the pseudorange from the Novatel receiver and satellite elevations calculated from the Yuma almanac parameters and the position information provided by the MMR. To eliminate discrepancies between datasets, Honeywell shared their normalization and CDF Overbounding functions for a direct comparison. Concurrent flight tests between Honeywell and the FAA were scheduled for the first week in July to determine some of the inconsistent data between SESAR and the FAA's flight test results. As a final recommendation, the DSIGMA Ad-Hoc team came up with a recommendation to "restrict the correlator design space in the SARPs and MOPS for early-minus-late correlators to an average spacing of 0.1 or less".

3.2 Honeywell SLS-4000 Block II

A system design approval letter for Honeywell's Block II update to their approved CAT-I capable system, the SLS-4000, was issued in October 2015. This update is expected to provide greater system availability in CONUS via updates to the Signal Deformation Monitor (SDM) that will allow use of PRNs 11 and 23 and thru finer multipath masking. These changes should alleviate the majority of brief service outages seen with the Block I version of the system. This update also allows for optional SBAS integration requiring a hardware update consisting of a WAAS-capable receiver and antenna. Use of SBAS for real-time ionospheric monitoring will allow the GBAS to not assume it's operating in a worst-case ionospheric environment at all times. This change should further increase system availability by lowering Protection Limit (PL) values. Honeywell also believes that use of the SBAS option could pave the way towards approval of auto-land and CAT-II capabilities. In addition, updates have been made to accommodate the system's use in low-latitude regions, though these updates will not be used in CONUS.

Operational approval of Block II updates at existing sites, Newark Liberty Int'l Airport (EWR) and George Bush Intercontinental Airport (IAH) will not be allowed until an MOA between the FAA and Honeywell Int'l to accommodate funding for FAA inspector training is finalized. This item is being actively worked.

3.3 System Design Approval (SDA) - Honeywell SLS-5000 (GAST-D)

Honeywell International (HI) is moving forward with submittals of safety documentation related to their GAST-D capable GBAS ground system, the SLS-5000, in parallel with final efforts to validate the GAST-D SARPS requirements at ICAO. The ICAO GAST-D GBAS SARPS will be the approval basis for this system as no FAA non-Fed specification exists for the GAST-D system.

Weekly teleconferences are being held between HI and the FAA. These calls address program planning, status and schedule, and technical review of GPS monitoring algorithms and safety analysis documentation. Additional calls are added as necessary to cover special topics. The FAA has also started work on assembling the approval panel for the SLS-5000. This panel will be composed of personnel from all FAA stakeholder organizations and will address issues related to both final approval of the ground system and integration of the system into the NAS.

3.4 Cargolux First Precision Approach to George Bush Intercontinental Airport (IAH)

On September 11th 2016, Cargolux flew their first GBAS approach to Runway 26L at George Bush Intercontinental Airport (IAH). After the first landing, personnel from Houston Airport Services, the FAA, and Honeywell provided the Cargolux crew with an in-depth tour of the GBAS facility on-site at IAH. GBAS is now installed as standard on all of Cargolux's Boeing 747-8F airframes.

3.5 GBAS Demonstration at San Francisco International Airport (SFO)

In an outstanding collaborative effort, San Francisco airport (SFO), local Western Service Area FAA, local ATC, FAA TRACON, Boeing, United Airlines and Delta Airlines successfully completed a GBAS demonstration at SFO this August.

San Francisco is not alone in expressing interest of what GBAS can provide for their airport environment and capacity. Recently more US airports are expressing interest in implementing GBAS as an additional precision approach capability.

United Airlines and Delta Airlines Taxiing out for the GBAS Demo with the Honeywell Portable GBAS in the foreground

Background on GBAS

GBAS has been operational as a non-Federal system at Newark International Airport (EWR since September 2012 and at George Bush Intercontinental Airport (IAH) since April 22, 2013.

Houston and Newark GLS approaches are flown on a regular basis by United Airlines and international airlines including Cathay Pacific, Emirates, British Airways, Lufthansa and Cargolux. United Airlines and Delta Airlines have the largest number of GLS equipped aircraft in the US and are champions for the GBAS technology. Over 3300 total GLS approaches have been flown at EWR and IAH as of August this year.

Boeing and Airbus remain strongly committed to GBAS and report an increasing GLS customer base and increased number of GLS equipped aircraft sales, with Boeing reporting over 1500 equipped aircraft and 47% of customers (over 60 airlines) choosing the GLS option. All new Boeing aircraft are GLS capable either as option or as standard equipment; GLS is Standard on the B787, B747–8 and B737MAX. Airbus has delivered GLS equipped aircraft to 31 different customers and noted the possibility to activate GLS on over 1100 additional fielded Airbus aircraft. All new Airbus aircraft offer GLS as option.

Why the SFO GBAS Demo?

SFO clearly has a few challenges: noise abatement, terrain, airspace constraints, weather causing frequent reduced visibility and a runway configuration with two sets of parallel runways 750 feet apart.

San Francisco airport, local Western Service Area FAA, local ATC, Northern California Terminal Radar Approach Control, Boeing, United Airlines and Delta Airlines got together to review the benefits of RNP and GLS for SFO. The overall objective was to demonstrate the benefits of combining RNP and GLS to different runways. To maximize the demonstration's potential, the airlines and Boeing worked with air traffic controllers at Northern California Terminal Radar Approach Control to design the approaches. Jeppesen provided the Navigation Database and charts. The procedures were pre-flown by Boeing, United and Delta Pilots using a 737 simulator. Boeing and SFO airport worked closely on a temporary location for the portable GBAS and on providing lighting for the displaced threshold approaches. The runway 28R GLS procedure targeted a displaced threshold some 2,000 feet farther down the runway than the normal touchdown zone.

The planned flight profiles included:
- Simultaneous Offset Instrument Approach (SOIAs) to Runways 28L, 28R
- Precision approach to runways without existing PA capability (19R, 10L)
- Closely Spaced Parallel Operations (CSPO) – Runways 28L, 28R
- 3.25 degree glide path angle approaches (for noise mitigation and increased vertical separation)
- Alternate touchdown/displaced threshold approaches (for potential wake mitigation and increased vertical separation)
- RNP to GLS/short turns to final (Potential Established on RNP application to reduce turn on distance to runway)

The demonstration flights were conducted in the evening hours of August 27, 2016 under VMC conditions. Airline, Boeing & FAA personnel were able to witness the approaches first hand. The flights were conducted as planned except for one approach to runaway 10L, which was discontinued above minimums because of incoming weather. The Honeywell portable GBAS performed flawlessly and flight operations and coordination was exceptional as addressed in the out-briefing with the following statement:

"Thank you NCT, Tower, SFO, United and Delta, Awesome Coordination!"

As a next step the team will work on a joint data analysis process which will support the evaluation of the GBAS demonstration for:
- Benefits to improved airport capacity and access during low visibility operations
- Reduction of neighboring airspace interference
- Flyability of approaches
- Noise & Emissions Reduction
- Lowest minima available
- Wake turbulence mitigation

A final report is expected by December 2016. Please also find the *Aviation Week* story on these flights at http://aviationweek.com/airlines-airports/boeing-delta-united-faa-join-forces-gls-demo-sfo.

3.6 ILS Localizer and VDB Overflights at FAA William J. Hughes Technical Center

Data analysis of the previous VDB/VDB adjacent channel data collection flights is continuing. The goal of those flight tests was to look at potential adjacent channel interference to/from the GBAS VDB signal. Some of this data has been shared with the RTCA SC-159 WG4 VDB Ad Hoc group.

Additional data looking at the adjacent channel compatibility of VOR and the ILS Localizer (LOC) with the VDB signal has been required to continue the work of the RTCA VDB Ad Hoc group. Additional data collection flights have been conducted by ANG-C32 to look at VOR and ILS/LOC signal strength levels on approach over the airport. Data has also been collected to look at the performance of the GBAS receiver when flying over an active Localizer transmitter antenna. The Localizer overflight data will help in determining requirements if GBAS is used for Guided Take Off applications. A concern is if the Localizer signal will cause an outage when flying over the Localizer antenna at low altitude. The recently collected data will be analyzed and shared with the VDB Ad Hoc group. The material from all the VDB flight tests will also be used for inputs to ICAO work.

The plot below shows VOR signal strength data collected on six approaches on 10/25/16. A 30dB attenuator is used to reduce the received signal strength to a level that does not exceed the maximum signal strength measurement level.

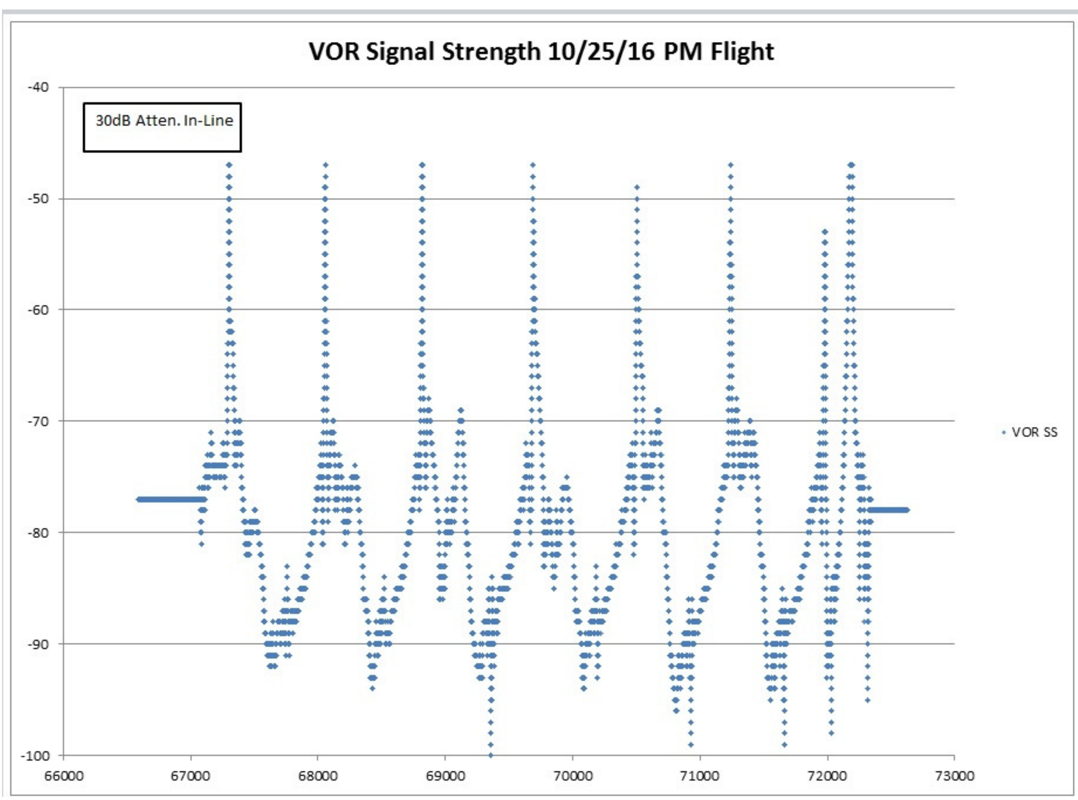

Figure 31 – VOR Signal Strength, 6 approaches flown on 10/25/16

Constellation Conditions

3.7 Notice Advisory to Navstar Users (NANUs)

The GPS constellation is designed to provide adequate coverage for the continental United States for the majority of the sidereal day. A NANU is a forecasted or reported event of GPS SV outages, and could cause concern if the SV outage(s) creates an insufficient geometry to keep the protection levels below the alert limits. See **Table 1** below for a list of NANU types.

NANUs that caused an interruption in service where Alert Limits are exceeded will be highlighted within the NANU summary (see **Table 2**). Although such an interruption is unlikely, the GBAS team closely tracks the NANUs in the event that post-data processing reveals a rise in key performance parameters.

NANU Acronym	NANU Type	Description
FCSTDV	Forecast Delta-V	Satellite Vehicle is moved during this maintenance
FCSTMX	Forecast Maintenance	Scheduled outage time for Ion Pump Ops / software testing
FCSTEXTD	Forecast Extension	Extends a referenced “Until Further Notice” NANU
FCSTSUMM	Forecast Summary	Gives exact time of referenced NANU
FCSTCANC	Forecast Cancellation	Cancels a referenced NANU
FCSTRESCD	Forecast Rescheduled	Reschedules a referenced NANU
FCSTUUFN	Forecast Unusable Until Further Notice	Scheduled outage of indefinite duration
UNUSUFN	Unusable Until Further Notice	Unusable until further notice
UNUSABLE	Unusable	Closes an UNUSUFN NANU with exact outage times
UNUNOREF	Unusable with No Reference NANU	Resolved before UNUSUFN issued
USABINIT	Initially Usable	Set healthy for the first time
LEAPSEC	Leap Second	Impending leap second
GENERAL	General Message	General GPS information
LAUNCH	Launch	Recent GPS Launch
DECOM	Decommission	Removed From constellation

Table 1 - NANU Types and Definitions

NANU	TYPE	PRN	Start Date	Start Time (Zulu)	End Date	End Time (Zulu)
2016036	FCSTDV	29	07/07/2016	2325	07/08/2016	1125
2016037	UNUSUFN	03	07/03/2016	1915	NA	NA
2016038	UNUSUFN	03	07/03/2016	1951	NA	NA
2016039	UNUSABLE	03	07/03/2016	1927	07/04/2016	0326
2016040	FCSTSUMM	29	07/08/2016	0011	07/08/2016	0610
2016041	FCSTDV	16	07/14/2016	2350	07/15/2016	1150
2016042	FCSTSUMM	16	07/15/2016	0031	07/15/2016	0420
2016043	FCSTDV	26	07/22/2016	0820	07/22/2016	2020
2016044	FCSTDV	16	07/19/2016	2345	07/20/2016	1145
2016045	FCSTSUMM	16	07/19/2016	2356	07/20/2016	0537
2016046	FCSTDV	24	07/26/2016	1520	07/27/2016	0320
2016047	FCSTDV	09	07/29/2016	0730	07/29/2016	1930
2016048	FCSTSUMM	26	07/22/2016	0842	07/22/2016	1324
2016049	FCSTSUMM	24	07/26/2016	1533	07/26/2016	2109
2016050	FCSTSUMM	09	07/29/2016	0755	07/29/2016	1253
2016051	FCSTDV	30	08/16/2016	1100	08/16/2016	2300
2016052	FCSTDV	31	08/18/2016	2045	08/19/2016	0845
2016053	FCSTSUMM	30	08/16/2016	1133	08/16/2016	1727
2016054	FCSTSUMM	31	08/18/2016	2112	08/19/2016	0340
2016055	UNUSUFN	08	08/26/2016	0211	NA	NA
2016056	UNUSABLE	08	08/26/2016	0211	08/26/2016	0924
2016057	FCSTDV	01	09/02/2016	0250	09/02/2016	1450
2016058	FCSTDV	20	09/08/2016	2030	09/09/2016	0830
2016059	FCSTSUMM	01	09/02/2016	0305	09/02/2016	0758
2016060	FCSTSUMM	20	09/08/2016	2041	09/09/2016	0231
2016061	FCSTDV	14	09/15/2016	1825	09/16/2016	1825
2016062	GENERAL	04	09/15/2016	NA	NA	NA
2016063	FCSTSUMM	14	09/15/2016	1844	09/16/2016	0111
2016064	FCSTDV	21	09/22/2016	1815	09/23/2016	0615
2016065	FCSTSUMM	21	09/22/2016	1841	09/22/2016	2355

Table 2 - NANU Summary

4. Meetings and Conferences

4.1 ICAO Navigation Systems Panel GBAS Working Group (GWG)

The GBAS Working Group (GWG) and Validation Working Group (VWG) met jointly on Aug 15th - through Aug 19th, 2016 at a Boeing Facility in Seattle. The GWG finished the compilation of material that completed the technical validation of the GBAS GAST D SARPs. That material will be submitted to the Navigation Systems Panel (NSP) meeting in Montreal, November 29 – December 9.

The primary topic of validation at the meeting was ionospheric gradient monitoring. A number of papers were presented that document the validation of the SARPs requirements. Airborne equipment MOPS requirements associated with ionospheric gradient monitoring still need to be coordinated with RTCA.

The GWG also agreed to new SARPs guidance material regarding VDB siting. The material is intended to ensure a minimum separation between the VDB transmitter and aircraft. An information paper was presented based on flight testing at the W.J.H. Technical Center that supported validation of the siting guidance.

The GWG agreed to changes to the SARPs that resolve issues related to the use of multiple VDB transmitters and the authentication requirements. The SARPs changes also need to be coordinated with associated changes to the airborne equipment MOPS.

Appendix A – GBAS Overview

A.1 GBAS Operational Overview

A GBAS is a precision area navigation system with its primary function being a precision landing system. The GBAS provides this capability by augmenting the GPS with real-time broadcast differential corrections.

A GBAS ground station includes four GPS Reference Receivers (RR) / RR antenna (RRA) pairs, and a Very High Frequency (VHF) Data Broadcast (VDB) Transmitter Unit (VTU) feeding an Elliptically Polarized VDB antenna. These sets of equipment are installed on the airport property where a GBAS is intended to provide service. The LGF receives, decodes, and monitors GPS satellite pseudorange information and produces pseudorange correction (PRC) messages. To compute corrections, the ground facility compares each pseudorange measurement to the range measurement based on the survey location of the given RRA.

Once the corrections are computed, integrity checks are performed on the generated correction messages to ensure that the messages will not produce misleading information for the users. This correction message, along with required integrity parameters and approach path information, is then sent to the airborne GBAS user(s) using the VDB from the ground-based transmitter. The integrity checks and broadcast parameters are based on the LGF Specification, FAA-E-3017, and RTCA DO-253D (Airborne LAAS Minimum Operational Performance Standards or MOPS).

Airborne GBAS users receive the broadcast data and use it to compute standardized integrity results. When tuning the GBAS, the user also receives the approach path for navigation with integrity assured. The GBAS receiver applies corrections to GPS measurements and then computes ILS-like deviations relative to the uplinked path providing guidance to the pilot. Airborne integrity checks compare protection levels, computed via the integrity parameters, to alert levels. Protection levels were determined based on allowable error budgets. The horizontal alert limit is 40m and the vertical is 10m at the GAST-C decision height of 200m. If at any time the protection levels exceed the alert limits, calculated deviations are flagged and the approach becomes unavailable. With the current constellation horizontal protection levels are typically 2.3m and vertical protection levels are typically < 5m with resulting availability of 100%.

One key benefit of the GBAS, in contrast to traditional terrestrial navigation and landing systems (e.g., ILS, MLS, TLS), is that a single GBAS system can provide precision guidance to multiple runway ends, and users, simultaneously. Only the local RF environment limits this multiple runway capability. Where RF blockages exist, Auxiliary VDB Units (AVU) and antennas can be added to provide service to the additional runways.

Figure 32 is provided as an illustration of GBAS operation with major subsystems, ranging sources, and aircraft user(s) represented.

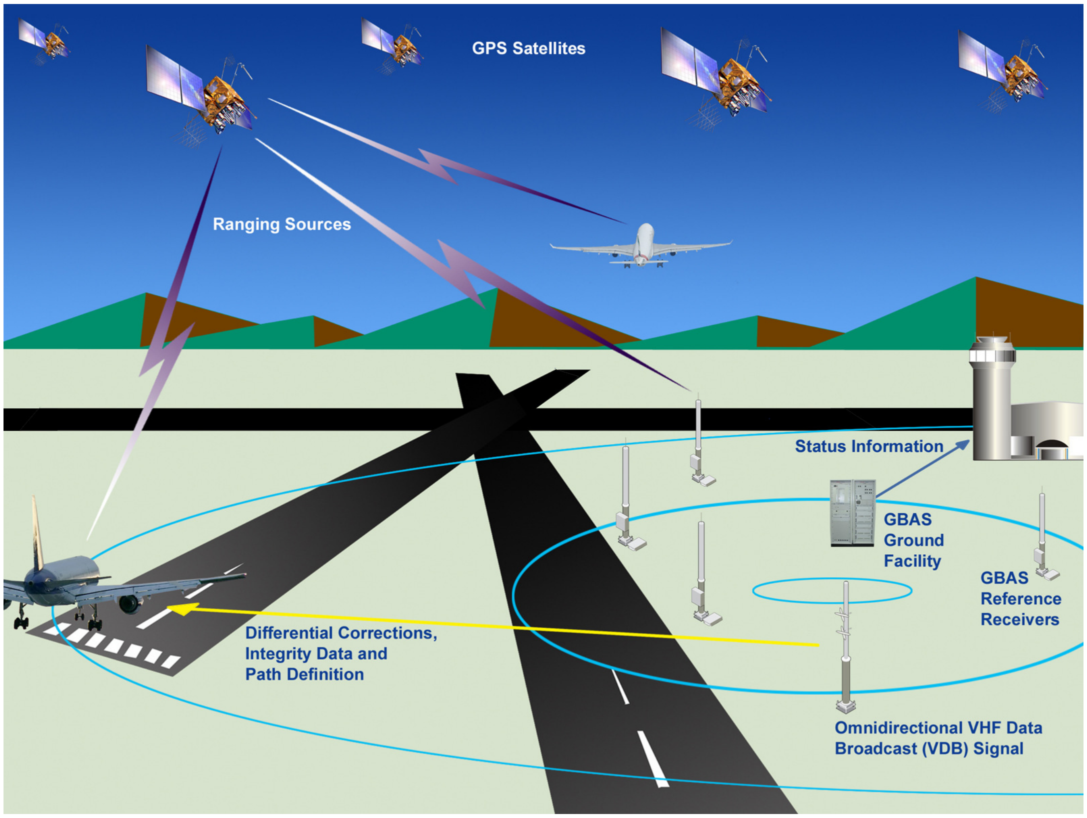

Figure 32 – GBAS Architecture Diagram

Appendix B - GBAS Performance and Performance Type

B.1 Performance Parameters and Related Requirements Overview

The GPS Standard Positioning Service (SPS), while accurate, is subject to error sources that degrade its positioning performance. These error sources include ground bounce multipath, ionospheric delay, and atmospheric (thermal) noise, among others. The SPS is therefore insufficient to provide the required accuracy, integrity, continuity, and availability demands of precision approach and landing navigation. A differential correction, with short baselines to the user(s), is suitable to provide precision guidance.

In addition to accuracy, there are failures of the SPS that are possible, which are not detected in sufficient time and can also cause hazardous misleading information (HMI). GBAS provides monitoring of the SPS signals with sufficient performance levels and time to alarm to prevent HMI.

The relatively short baselines between the user and the GBAS reference stations, as well as the custom hardware and software, is what sets GBAS apart from WAAS. Use of special DGPS quality hardware such as employment of MLA's serves to mitigate the multipath problems, while the GBAS software monitors and corrects for the majority of the remaining errors providing the local user a precision position solution.

The LAAS Ground Facility is required to monitor and transmit data for the calculation of protection parameters to the user. The GBAS specification also requires monitoring to mitigate Misleading Information (MI) that can be utilized in the position solution. These requirements allow the GBAS to meet the accuracy, integrity, availability, and continuity required for precision approach and landing navigation.

There are three Performance Types (PT) defined within the LAAS Minimum Aviation System Performance Standards (MASPS). The three performance types, also known as Categories, (i.e., Cat I, and Cat II/III), all have the same parameters but with different quantity constraints. For the purposes of this report, the LTP assumes Cat I Alert Limits and hardware classification.

B.2 Performance Parameters

This section highlights the key parameters and related requirements used to depict GBAS system performance in this report. In order to provide the reader a clearer understanding of the plots provided, a little background is being provided below.

Cat I precision approach requirements for GBAS are often expressed in terms of Accuracy, Integrity, Availability, and Continuity. For clarity the use of these four terms, in the context of basic navigation, are briefly described below:

- **Accuracy -** is used to describe the correctness of the user position estimate that is being utilized.
- **Integrity** – is the ability of the system to generate a timely warning when system usage should be terminated.

- **Availability** - is used to describe the user's ability to access the system with the defined Accuracy and Integrity.
- **Continuity** - is used to describe the probability that an approach procedure can be conducted, start to finish, without interruption.

B.2.1 VPL and HPL

Vertical and Horizontal Protection Levels (VPL and HPL) parameters are actively monitored since the GBAS is required to perform with a worst case constellation and geometry scenario. VPL / HPL parameters are directly tied to constellation geometry and when combined with pseudorange errors affect the SPS position estimate and time bias. Monitoring the VPL and HPL in the GBPM gives a valid picture of what the user is experiencing. The protection levels are compared against the alert limits of the appropriate GBAS service level (GSL). In the event the protection levels exceed the alert limit, an outage will occur (See section 6 for GBAS site specific outages).

B.2.2 B-Values

B-values represent the uncorrectable errors found at each reference receiver. They are the difference between broadcasted pseudorange corrections and the corrections obtained excluding the specific reference receiver measurements. B-values indicate errors that are uncorrelated between RRs. Examples of such errors include multipath, receiver noise, and receiver failure.

B.2.3 Performance Analysis Reporting Method

For a given configuration, the LTP's 24-hour data sets repeat performance, with little variation, over finite periods. The GBAS T&E team can make that statement due to the continual processing of raw LTP data and volume of legacy data that has been analyzed from the LTP by the FAA and academia. Constellation and environmental monitoring, in addition to active performance monitoring tools such as the web and lab resources provide the GBAS T&E team indications for closer investigation into the presence, or suspicion, of uncharacteristic performance.

Data sets from the LTP ground and monitoring stations are retrieved on a weekly basis and processed immediately. A representative data-day can then be drawn from the week of data to be formally processed. The resultant performance plots then serve as a snapshot of the LTP's performance for the given week. These weekly plots are afterward compared to adjacent weeks to select a monthly representative set of plots.

Appendix C - LTP Configuration and Performance Monitoring

C.1 Processing Station

The LTP Processing Station is an AOA-installed operational GBAS system. It is continually operational and is used for flight-testing, in addition to data collection and analysis summarized in this report. As an FAA test system, the LTP is utilized in limited modified configurations for various test and evaluation activities. This system is capable of excluding any single non-standard reference station configuration from the corrections broadcast. The performance reporting of the system is represented only from GBAS standard operating configurations.

C.1.1 Processing Station Hardware

The processing station consists of an industrialized Central Processing Unit (CPU) configured with QNX (a UNIX-type real time OS). It then collects raw reference station GPS data messages while processing the data live. It also collects debugging files and special ASCII files utilized to generate the plots found in this report. These collected files are used for component and system level performance and simulation post processing.

The CPU is also configured with a serial card that communicates in real time with the four reference stations through a Lantronix UDS2100 serial-to-Ethernet converter. The reference stations continuously output raw GPS messages to the CPU at a frequency of 2 Hz. Data to and from the reference station fiber lines is run through media converters (fiber to/from copper). The CPU then generates the GBAS corrections and integrity information and outputs them to the VDB.

The VDB Transmitter Unit (VTU) is capable of output of 80 watts and employs a TDMA output structure that allows for the addition of auxiliary VDBs (up to three additional) on the same frequency for coverage to terrestrially or structure blocked areas. The LTP's VTU is tuned to 112.125 MHz and its output is run through a band pass and then through two cascaded tuned can filters. The filtered output is then fed to an elliptically polarized three bay VHF antenna capable of reliably broadcasting correction data the required 23 nautical miles (see Protection Level Maps at http://laas.tc.faa.gov for graphical representation).

Surge and back-up power protection is present on all active processing station components.

C.1.2 Processing Station Software

Ohio University (OU) originally developed the GBAS code through an FAA research grant. Once the code reached a minimum of maturity, OU tested and then furnished the code to the FAA (circa 1996). It was developed using the C programming language under the QNX operating system. QNX was chosen because of its high reliability and real-time processing capability. This LTP code has been maintained by the GBAS T&E team since that time and has undergone numerous updates to incorporate evolving requirements, such as the inclusion of Cat III.

The software stores the precise survey data of the four GBAS reference station antennas (all RRA segments). Raw GPS data (i.e., range and ephemeris info) is received via four GPS receivers. The program cycles through the serial buffers and checks for messages, if one is found, it gets passed to a decoding function. From there, it is parsed out to functions according to message type and the information from the messages is extracted into local LTP variables. Once the system has received sufficient messages, the satellite positions are calculated in relation to the individual reference receivers. Type 1, 2, 4, 11 messages containing differential corrections, integrity values, GS information, and approach path data are then encoded and sent to the VDB via a RS-232 connection. Each of the four message types are encoded separately and sent according to DO-246D standards.

C.2 Reference Stations

There are four reference stations included in the FAA's LTP as required in the GBAS specification. The LTP's reference stations are identified as LAAS Test (LT) sites; there were originally five LT sites (LT1 through LT5), excluding LT4. LT4 was originally used for the L1/L2 site (**Figure 33**).

Each reference station consists of two major component systems. The first is a high quality, GNSS antenna (ARL-1900) manufactured by BAE Systems. The second is the reference receiver.

Figure 33 - The BAE GNSS Multipath Limiting Antenna (MLA)

C.2.1 The BAE ARL-1900 GNSS Multipath Limiting Antenna (MLA)

The BAE Systems ARL-1900 is an innovative, single feed, GNSS antenna that is approximately 6 feet high, and weighs about 35 pounds. The receiving elements are configured in an array, and when combined allow reception of the entire GNSS (Global Navigation Satellite System) band. This antenna is also capable of the high multipath rejection as required by the LAAS specification.

Multipath is a phenomenon common to all Radio Frequency (RF) signals and is of particular concern in relation to DGPS survey and navigation. It is simply a reflection of a primary signal that arrives at a user's equipment at a later time, creating a delay signal that can distort the primary if the reflection is strong. Reflected multipath is the bouncing of the signal on any number of objects including the local water table. Signals that reflect off the earth surface are often referred to as ground-bounce multipath. In all cases, the path length is increased. This path length is critical in GPS since the ranging is based on the signal's Time of Arrival (TOA). This causes a pseudorange error, for the SV being tracked, proportional to the signal strength. The BAE provides at least 23 dB of direct to indirect (up/down) pattern isolation above 5 degrees elevation. These multipath induced pseudorange errors can translate directly into a differential GPS position solution, which would be detrimental to applications such as GBAS. Multipath limiting antennas, such as the BAE Systems ARL-1900, were therefore developed to address the multipath threat to differential GPS and attenuate the ground multipath reducing the error. The ARL-1900 antenna characteristics also mitigate specular reflections from objects. The antenna's polarization (right hand circular polarized, or RHCP), provides a pattern advantage and reflective LHCP signals, which is left hand circular polarized.

Appendix D - GBPM Configuration

The Ground Based Performance Monitor is the primary performance monitoring tool for the LTP and the Honeywell SLS-4000 systems. The system uses the received VDB broadcast type 1, 2, 4, and 11 messages from the ground station being monitored along with raw GPS data in order to compute the position of the monitor station. The position calculated from this data is compared to the position of the precision-surveyed GBAS grade GPS antenna, which is used to identify positioning errors.

The GBPM's Novatel OEM-V receiver logs range and ephemeris messages, which provide the necessary pseudorange and carrier phase measurements, as well as satellite position information. VDL messages are then received and separated into each of the DO-246D GBAS message types and decoded.

Data is collected in 24-hour intervals and saved to a .raw file without interruption. This data is used to post-evaluate system performance. In addition to the raw file, live data is transferred from each offsite monitor once per minute to our local database. Users can then access the data through an interactive website by means of tables, charts, and graphs hosted by the Navigation Branch at the FAA. The web address for this service is http://laas.tc.faa.gov.

Analysis of GBPM data is critical for closely observing the LTP and SLS performance behavior. The GBPM data output package contains several plots that can quickly illustrate the overall performance picture of the GBAS. The most useful plots available for performance summary purposes are *Vertical and Horizontal User Error versus Time*. These two plots are often used for preview performance analysis because the "user" GPS sensor position is known and stationary. The known position (precision survey) of the GBPM GPS sensor is compared directly to the computed user position. Typical LTP Vertical and Horizontal user error has an average well within the +/- 1-meter range.

Figure 34 is one of the GBPM's that was built by the Navigation Branch. Some of the major components include a retractable KVM to check the current status of the monitor, CISCO router with a T1 line back to our lab at ACY for data collection and maintenance, Power Distribution Unit (PDU) for a means remote access to bring power outlets back up if they become unresponsive, Novatel GPS Receiver, Becker VDB Receiver, QNX CPU, and an uninterruptable power supply.

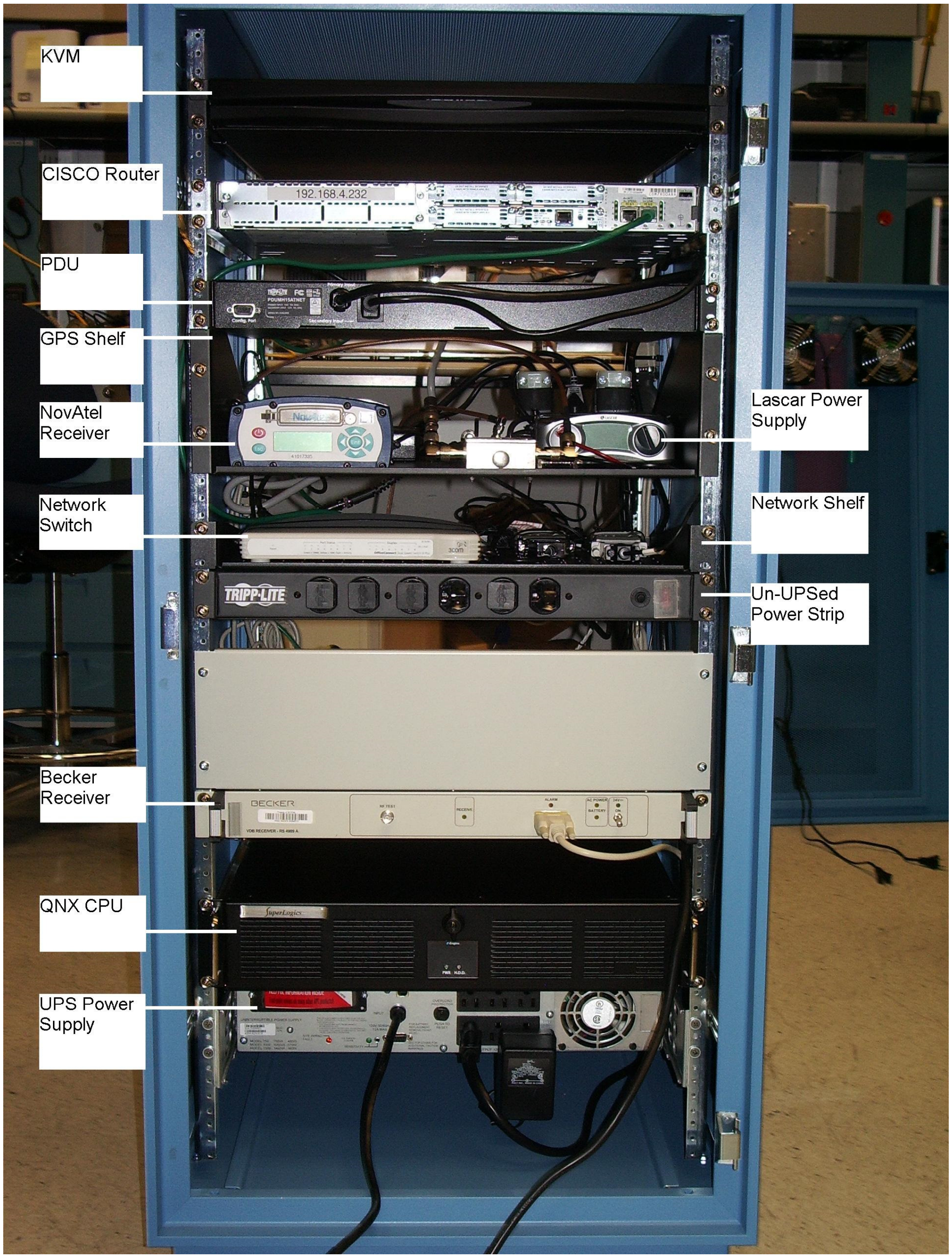

Figure 34 - Ground Based Performance Monitor (GBPM)

Glossary of Terms

—A—

ACY
  Atlantic City International Airport 3, 4

—C—

CPU
  Central Processing Unit 33

—E—

EWR
  Newark Liberty International Airport 4

—F—

FAA
  Federal Aviation Administration 3

—G—

GBAS
  Ground Based Augmentation System 3

GBPM
  Ground Based Performance Monitor 3

GIG
  Galeão International Airport 4

GNSS
  Global Navigation Satellite System 34

GPAR
  GBAS Performance Analysis Report 3

GSL
  GBAS Service Level 32

—H—

HI
  Honeywell International 3

HPL
  Horizontal Protection Level 32

—I—

IAH
  George Bush Intercontinental Airport 4, 8

—L—

LHCP
  Left Hand Circular Polarized 35

LT
  LAAS Test 34

—M—

MASPS
  Minimum Aviation System Performance Standards 31

MI
  Misleading Information 31

MLA

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